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OXY-HYDROGEN FLAME FOR CUTTING OF STEELS

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The paper deals with oxy-hydrogen cutting of steel plates. The first part deals with calculation of the combustion efficiency of an oxy-hydrogen flame. A device for supply of a hydrogen-oxygen mixture is described. The main part of the paper is focused on oxy-hydrogen cutting and its advantages. The main conclusions show that the cut surface is flat and very smooth, the heat-affected zone is very narrow, and the cutting speed is relatively high.

Key words: *oxy-hydrogen cutting, efficiency of combustion, heat-affected zone (HAZ)*

Kisik-vodikov-plamen za rezanje čelika. U članku se razmatra rezanje čeličnih limova s kisik-vodikovim plamenom. Prvi dio članka govori o proračunu iskoristivosti sagorijevanja vodika s kisikom. Nakon toga opisana je naprava za proizvodnju kisik-vodikove mješavine. Glavni dio članka usredotočen je na rezanje s kisik-vodikovim plamenom. Prikazane su prednosti rezanja s kisik-vodikovim plamenom. Najvažniji zaključci su: površina reza je glatka i ravna, prijelazno područje toplinskog utjecaja je vrlo usko, brzina rezanja je relativno visoka.

Ključne riječi: *rezanje s kisik- vodikovim plamenom, efektivnost sagorijevanja, prijelazno područje toplinskog utjecaja*

INTRODUCTION

Thermal cutting, i.e. gas cutting, is a wide-spread technology. In practical applications, gases such as propane-butane and acetylene prevail. Hydrogen is practically not used due to its high production cost and its explosiveness.

In the first part of the paper, a device for production of an oxygen-hydrogen mixture is described and some basic characteristics of oxy-hydrogen cutting are indicated.

BASIC CHARACTERISTICS OF COMBUSTION OF HYDROGEN AND OXYGEN

Hydrogen is a colourless, odourless, and tasteless elementary gas. It is not poisonous. In nature it is rarely found in its atomic form. With an atomic weight of 1,008, it is the lightest known substance. It is flammable. A flame temperature in hydrogen combustion in air attains 1700 °C, and in oxygen 2400 °C. When mixed with air, hydrogen forms an explosive mixture (an explosive gas). Its ignition temperature is 560 °C whereas its explosion range is from 4 to 75 vol. % at atmospheric pressure.

The equation showing the chemical reaction of complete combustion of hydrogen and oxygen is as follows:

$$H_2 + 0.5\ O_2 \rightarrow H_2O,$$
$$2\ kg + 16\ kg \rightarrow 18\ kg.$$

The main properties of hydrogen are as follows:
- the lightest gas (fourteen times lighter than air),
- high thermal conductivity (seven times higher than that of air),
- high diffusibility (five times higher than that of methane),
- minimum energy required for ignition (five times lower than that required for petrol),
- high rate of combustion (eight times higher than that of petrol) [1 - 4].

THERMAL CUTTING OF STEELS

Combustion gas cutting using oxygen is one of the processes of metal cutting employing a high-temperature reaction of oxygen with the parent metal. With oxidation-resistant materials, the reaction is promoted by the addition of chemicals or metal powder.

Typical constituents of oxygen cutting are an oxygen jet, a mixture of oxygen and a combustion gas, an oxygen lance, a chemical agent, and metal (iron) or ceramic powder.

With regard to the material and requirements of production, the three most important processes are the following ones:

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- oxy-fuel gas cutting,
- plasma cutting,
- laser cutting.

Oxy - fuel gas cutting is a cutting process in which the flame of a combustion gas and oxygen is used for heating, and pure oxygen for metal burning.

For oxygen cutting of a metal, following conditions should be fulfilled:

A: The metal should burn in oxygen and the oxides formed shall be liquid so that they may be easily removed from the kerf. In gas cutting of low-alloy steel, approximately 50 to 80 % of the material is burnt and 20 to 50 % is molten.

B: The ignition point of the metal should be lower than its melting point. Steel with 0,1 % C has an ignition point of 1160 °C whereas its melting point is at 1526 °C. The ignition point increases with an increased C content whereas the melting point decreases.

C: The oxides formed in combustion should have a lower than or approximately the same melting point as the pure metal.

D: Thermal conductivity of the metal should be as low as possible whereas as much heat as possible should be generated during cutting [4 - 8].

HEATING EFFICIENCY

Heating efficiency (heat losses in the ambient air):

$$\eta = \frac{\dot{Q}}{\dot{Q}_{\text{flame}}} \ / \ \% \tag{1}$$

where

$$\dot{Q} = \frac{\dot{Q}_{\text{dov}}}{t_0}, \tag{2}$$

$\dot{Q}_{\text{flame}}$ - the heat energy of the flame per time,
$\dot{Q}_{\text{dov}}$ - the heat supplied to the workpiece by the heating flame,
t_0 - the time required to attain the final temperature of the workpiece heated.

The heat balance can be shown schematically with the blowpipe/workpiece system in Figure 1.

The heat flow supplied to the system equals $\dot{Q}_{\text{flame}}$ whereas the outgoing heat flows are:
$\dot{Q}_s$ - heat flow due to flame radiation,
$\dot{Q}_k$ - heat flow due to heat transmission from the heated workpiece to the ambient air and to the insulating material below.

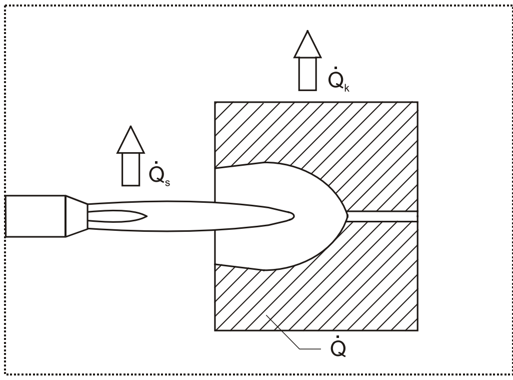

Figure 1. **Schematic representation of a measuring device for heating efficiency of the oxygen-hydrogen flame**
Slika 1. **Shematski prikaz naprave za mjerenje toplotnog iskorištenja kisik vodikovog plamena**

Theoretical $\dot{Q}_{\text{dov}}$ and $\dot{Q}_{\text{flame}}$ could be calculated by equations (3) and (4):

$$\dot{Q}_{\text{dov}} = \int_{T_{ok}}^{T_k} m \cdot c_p \mathrm{d}T, \tag{3}$$

$$\dot{Q}_{\text{flame}} = q_{v,\text{gas}} \cdot H_{i,\text{gas}} \tag{4}$$

where:

T_k - the final temperature of the workpiece heated / K,
T_{ok} - the ambient temperature,
m - the mass,
c_p - the specific heat of the workpiece /(J/kgK),
$\mathrm{d}T$ - the change of temperature / K,
$q_{v,\text{gas}}$ - the volume flow rate of the fuel gas /(m^3/s),
$H_{i,\text{gas}}$ - the lower calorific value of the fuel gas /(J/m^3).

After the experiments, it can be stated that the heating efficiency of the oxy-hydrogen flame attains approximately 46 % whereas that of the oxy-acetylene flame attains 17 % only [1, 2, 6 - 8].

DESCRIPTION OF THE OXY-HYDROGEN CUTTING PROCESS

Hydrogen production for practical cutting with a Greengas device

Hydrogen can be produced in practice in the following ways:

- with partial combustion of hydrocarbons: $C_4H_{10} + 2CO_2 \Leftrightarrow 4CO + 5H_2$,
- with catalytic decomposition of hydrocarbons (e.g. methane): $CH_4 \Leftrightarrow C + 2H_2$,
- with the catalytic reforming process of the natural gas: $CH_4 + H_2O \Leftrightarrow CO + 3H_2$,

- with gasification of coal or coke: $C + H_2O \Leftrightarrow CO + H_2$,
- with water electrolysis: $2\ H_2O \Leftrightarrow 2\ H_2 + O_2$.

In the Greengas device, water electrolysis is used to produce hydrogen [5 - 8].

Water electrolysis

Water electrolysis is a reducing-oxidizing reaction in which oxidation and reduction are carried out in separate chambers. Oxidation is carried out at the anode and reduction at the cathode.

The device for the water electrolysis is shown schematically in Figure 2.

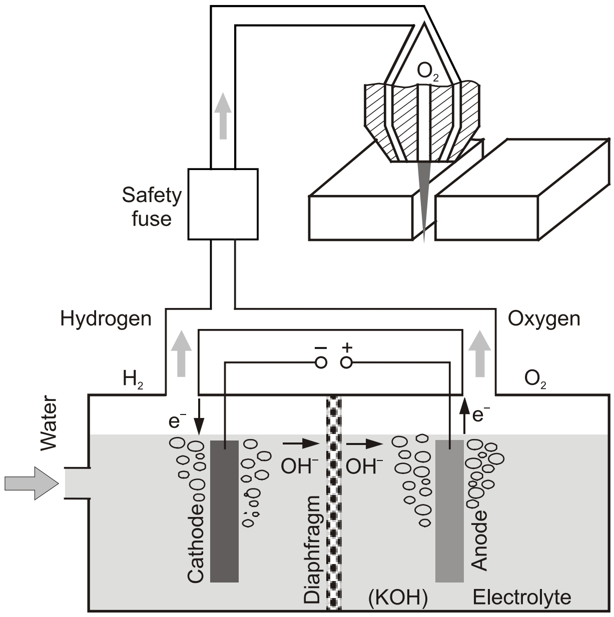

Figure 2. **Principle of operation of the device for production of the oxygen-hydrogen mixture for cutting**
Slika 2. **Načelna shema rada naprave za proizvodnju kisik-vodikove mješavine za rezanje**

If a sufficiently high DC voltage is supplied to the electrode, electrolysis, i.e., chemical reactions, will occur at the electrodes. At the cathode (–), hydrogen ions will transform into gaseous hydrogen (H_2) whereas at the anode (+) oxygen ions will transform into gaseous oxygen (O_2). Both gases can then be stored into two separate gas tanks.

Developments in the field of electronics provided chances for modifications of the conventional process of electrolysis known for a century. In the conventional process, there are two gas tanks, one with positive polarity, the other with negative one. The GREENGAS device (Figure 3.) has only one gas tank, which means that two parts of hydrogen and one part of oxygen will collect in the tank. The mixture obtained is called Greengas by its manufacturer. With the usual procedure, the electrodes are worn-out asymmetrically. They need to be cleaned too. With the Greengas procedure, the manufacturer claims that the electrodes will wearout uniformly and be cleaned simultaneously. According to the manufacturer, the electrolyte needs to be poured in the device only once a year if the device is permanently used. Since the electrodes are of the self-cleaning type, common potable water may be used.

Figure 3. **Device for production of oxygen-hydrogen gas mixture for cutting and other gas flame processes**
Slika 3. **Prikaz uređaja za proizvodnju kisik-vodikove mješavine za rezanje i druge plamenske postupke**

Practical application of hydrogen cutting

In gas cutting, the parent metal is burning at the ignition point in an oxygen jet. The parent metal is heated by the oxy-fuel flame to the ignition point. At this temperature, the material oxidizes in the atmosphere of oxygen. The metal will transform into a metal oxide.

The cutting process can be divided into three steps (Figure 4.):
- metal heating with the flame to the ignition point,
- metal oxidation with oxygen,
- blowing of slag out of the kerf.

Practical application of gas cutting with oxygen and hydrogen is shown in Figure 4.

Description of the equipment

The gas cutting equipment is of two types depending on the technique used, i.e.:
- the equipment for manual cutting, or
- the equipment for machine cutting.

Figure 4. **Practical cutting with oxy-hydrogen flame**
Slika 4. **Prikaz praktičnog rezanja s kisik-vodikovim plamenom**

Manual cutting is used mainly for rough machining, in which case great accuracy of machining is not required, or there are no requirements regarding kerfs.

Machine cutting, however, is used to attain accurate and quality machining, and particularly with larger workpieces.

Types of nozzles for oxygen cutting

Cutting nozzles and their shapes usually do not depend on the combustion gas used but the case is different with the oxy-hydrogen flame. The nozzle-bores are, namely, shaped for the oxy-hydrogen flame so as to ensure a stable flame and appropriate heating of the material to be cut with regard to its thickness.

Schematics of two nozzles and, consequently, two different flames for gas cutting are shown in Figure 5.

Machine cutting requires some additional units depending on the kind of the process. Some of them are:
- a mechanism displacing the blowpipe along the workpiece,
- a mechanism to fix the blowpipe,
- a cutting table for positioning the workpiece,
- devices for positioning the workpiece on the cutting table and displacing it,
- an automatic ignition device for blowpipe ignition.

The cutting equipment can include very simple manual devices or even computer-controlled devices. The equipment for manual cutting is similar to that for machine cutting but it differs as regards gas pressure regulation, cutting speed and establishment of the cutting process. Many devices are adapted to specific requirements of different cutting applications, e.g. edge preparation, tube cutting, position cutting [1 - 3].

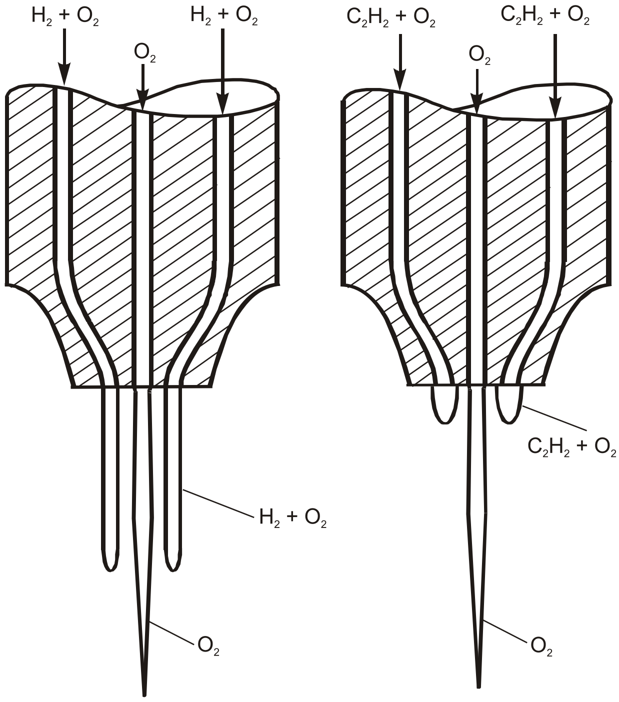

Figure 5. **Comparative sketches of nozzles and flames for oxygen-acetylene and oxygen-hydrogen cutting**
Slika 5. **Slikovna usporedba sapnica za rezanje i plamena za kisik-acetilensko i za kisik-vodikovim rezanjem**

ANALYSIS OF RESULTS

Heat-affected zone (HAZ)

The temperature of the oxy-hydrogen flame is by 500 °C lower than that of the oxy-acetylene flame and also lower than that of the propane-butane flame. This affects the cutting process, the size of the heat-affected zone and deformation of the workpieces. In practical oxy-hydrogen cutting the workpieces showed less deformation and a narrower heat-affected zone as in oxy-acetylene cutting. The macrographs in Figure 6. show the difference between the two heat-affected zones produced with different combustion gases.

Roughness of the cut face

The quality of a cut face is defined in standard DIN 2310-3 which distinguishes:
- tolerances of length; classes A and B are distinguished with regard to workpiece thickness and length,
- roughness of a cut face.

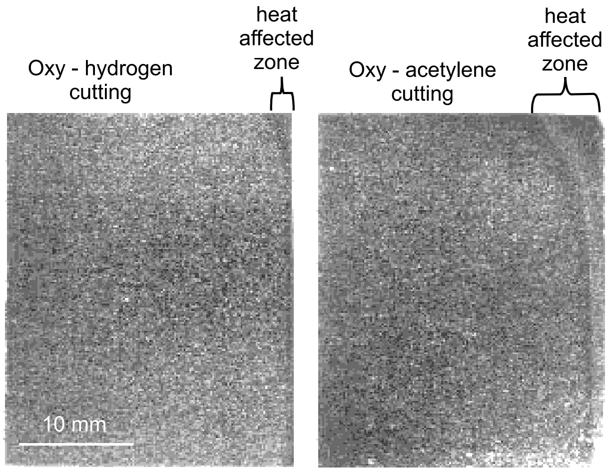

Figure 6. **Comparison of two cut workpieces with the heat affected zone, which were cutted with two different gas-mixture**
Slika 6. **Usporedba prijelaznih područja toplinskog utjecaja na radnim komadima, koji su bili odrezani s različitim plinskim mješavinama**

Roughness of the surfaces cut depends on:

n - the deviation of a flame track from the vertical workpiece axis,
u - the deviation of the cut face from the vertical at the workpiece edge,
R_z - the height of uneveness of the profile in accordance with ISO 4287/1-1984,
r - the workpiece edge radius.

The surface roughness was measured at workpieces of 80 mm in thickness (Figure 7.).

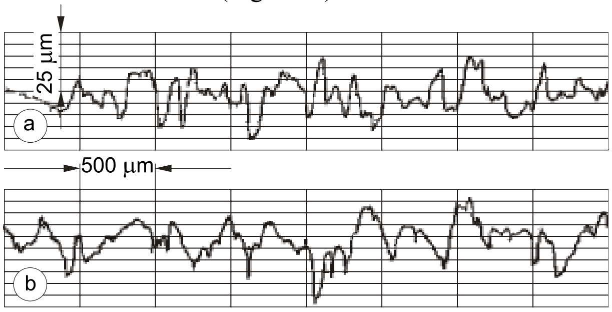

Figure 7. **Comparison of roughness of the surfaces cut with different gases; a) oxygen-hydrogen cutting, b) oxygen-acetylene cutting**
Slika 7. **Usporedba hrapavosti površina odrezanih različitim plinovima; a) rezanje s kisik-vodikovim plamenom, b) rezanje s kisik-acetilen plamenom**

Surface hardness

In all the experiments steel Fe360B in accordance with EN 25000 was used. The table below gives a comparison of hardness values for the parent metal and the cut faces [2].

Table 1. **Comparison of hardness value**
Tablica 1. **Usporedba vrijednosti tvrdoće**

Material thickness / mm	Hardness PM / HV	Hardness AC / HV	Hardness H / HV
8	103	133	132
15	101	140	141
30	104	182	183
45	103	172	175
80	109	180	177

Hardness PM - the hardness of the parent metal
Hardness AC - the hardness of the surface cut with oxy-acetylene mixture
Hardness H - the hardness of the surface cut with the oxy-hydrogen mixture

CONCLUSIONS

The initial studies of oxy-hydrogen cutting of low-alloy steel showed some advantages in comparison with cutting using other gases (CH_2, C_2H_2, C_2H_8), i.e.:

- the cut face is straighter and smoother,
- the HAZ is very narrow and less affected,
- hardness at the cut face is approximately the same,
- cutting speed is by up to 10 % higher,
- from the economic point of view, the use of $O_2 + H_2$ mixture pays,
- advantages of the use of $O_2 + C_2H_2$ are most evident in cutting of thicker materials.

The only disadvantages of the use of $O_2 + H_2$ are the risks involved in work with this gas mixture and a possible occurrence of minor explosions resulting in safety-fuse melting.

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